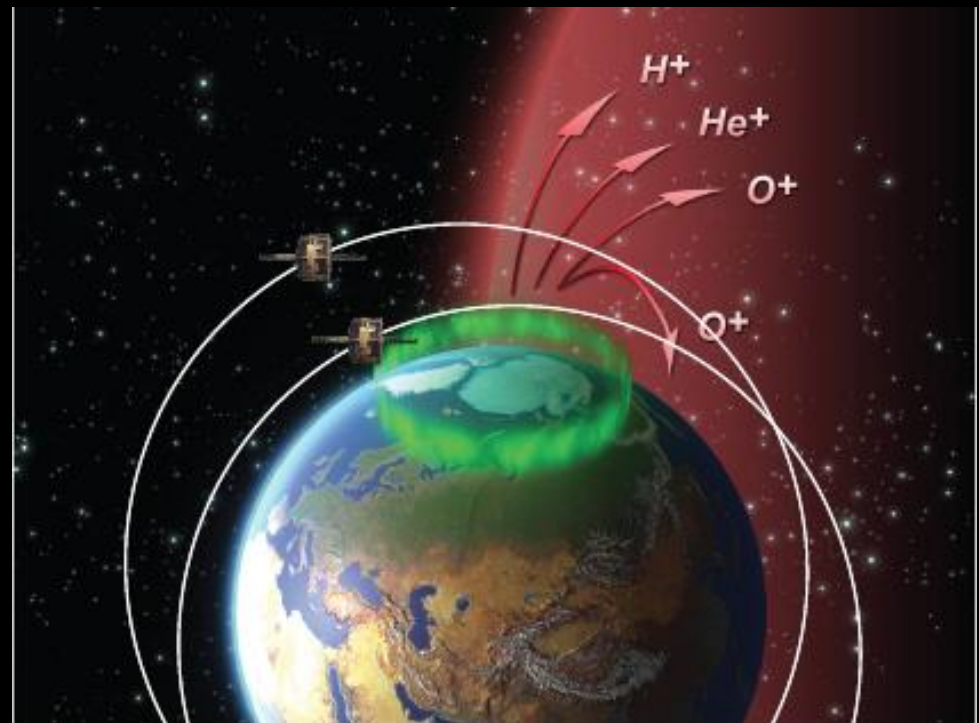


Miniaturized Ion and Neutral Mass Spectrometer for CubeSat Atmospheric Measurements

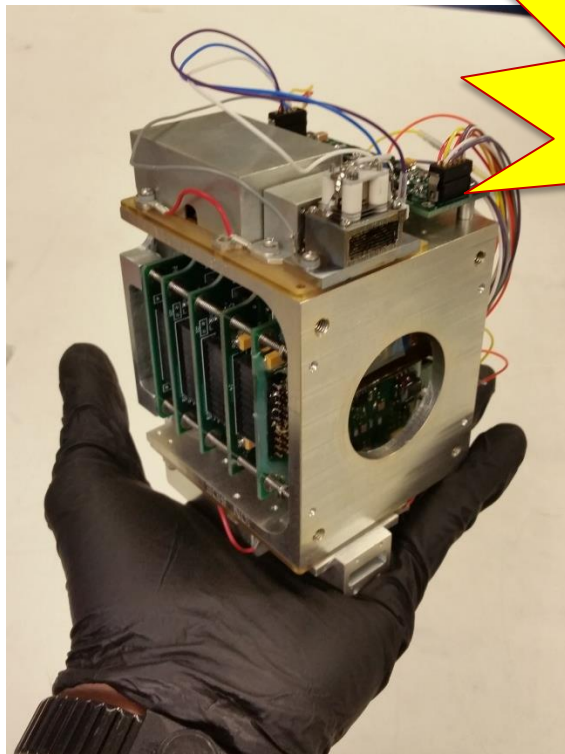
M. Rodriguez, N. Paschalidis, S. Jones, E. Sittler, D. Chornay, P. Uribe, NASA Goddard Space Flight Center

T. Cameron, ADNET

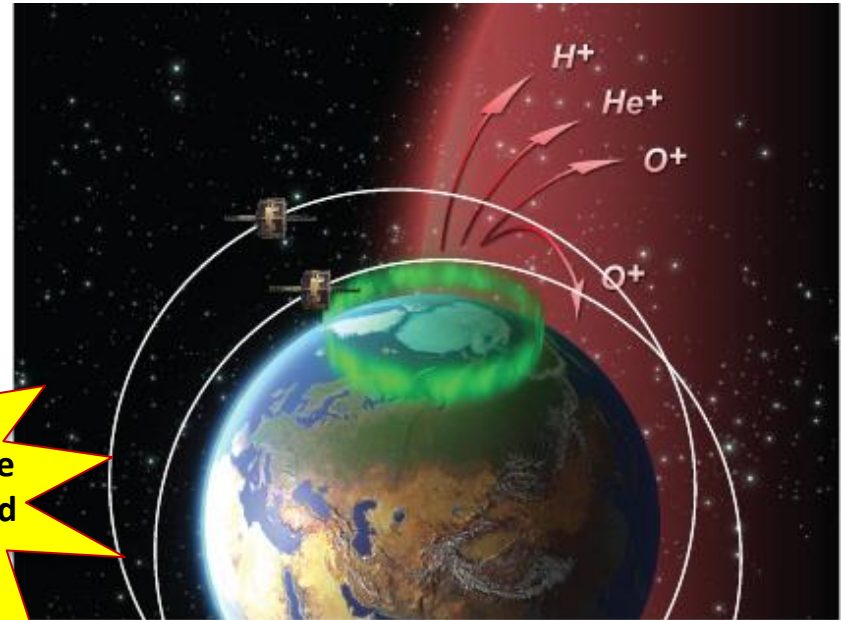


Mini Ion Neutral Mass Spectrometer for Measuring Ionospheric Composition on EXOCUBE

Demand is high for in situ measurements of atmospheric neutral and ion composition and density, not only for studies of the dynamic ionosphere-thermosphere-mesosphere system but simply to define the steady state background atmospheric conditions.



**High Quality Science
in an unprecedented
small package!!**



This ion/neutral mass spectrometer uses Pre Acceleration and Gated Time of Flight analysis to differentiate species and is designed specifically to resolve neutral and ionized H, He, and O; the instrument has the potential for adding additional capabilities

Technology Readiness Level: 8

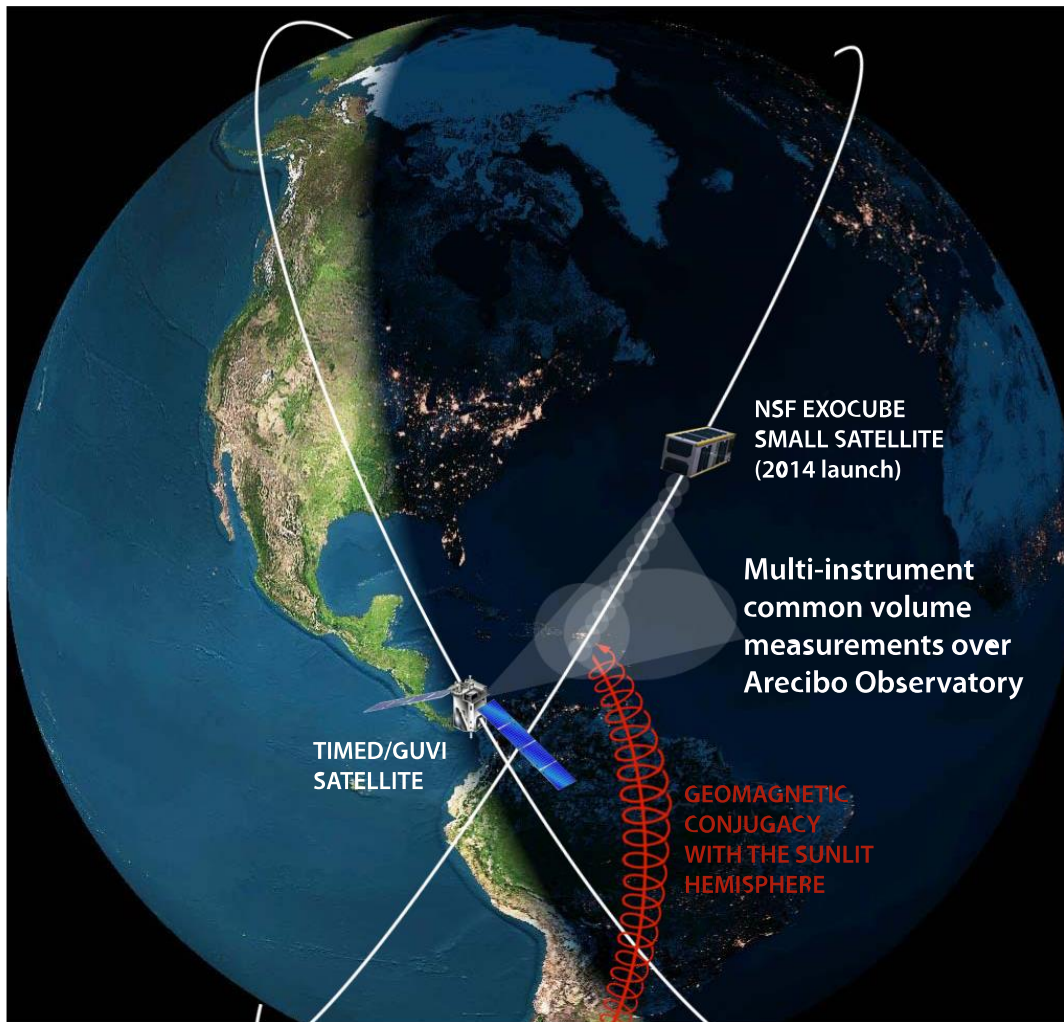
Ionospheric and Thermospheric Science

High-resolution, in situ measurements of [O], [H], [He], [O+], [H+], [He+], & total ion density, will serve as benchmarks for upper atmospheric composition and abundances and thus enable investigations regarding:

- ☐ Global atmospheric structure and climatology
- ☐ Atmospheric model validation
- ☐ Constraints to forward-modeling of airglow emissions
- ☐ Characterization of exospheric behavior
- ☐ Quantification of charge exchange processes
- ☐ Characterization of storm-time behavior and response



**First in situ [H]!
Minimal in situ [O] or
[He] since 1983!**



The upcoming NSF EXOCUBE mission will provide the first-ever *in-situ* measurements of ion and neutral densities, including [H] and [O], for unprecedented global and storm-time characterization of the thermosphere and exosphere.

The first-ever empirical estimation of global atomic hydrogen density [H] in the thermosphere and exosphere (from 90 km to 3 R_E) was enabled by TIMED/GUVI measurements of ultraviolet airglow emission

(Waldrop and Paxton, JGR, 2013)

Specification of [H] over Arecibo Observatory in turn allows the first-ever empirical estimation of:

- atomic oxygen density [O]
- exospheric temperature
- photoelectron flux from the conjugate hemisphere
- key chemical reaction rates

via coincident measurements of optical airglow emissions and incoherent radar scatter.

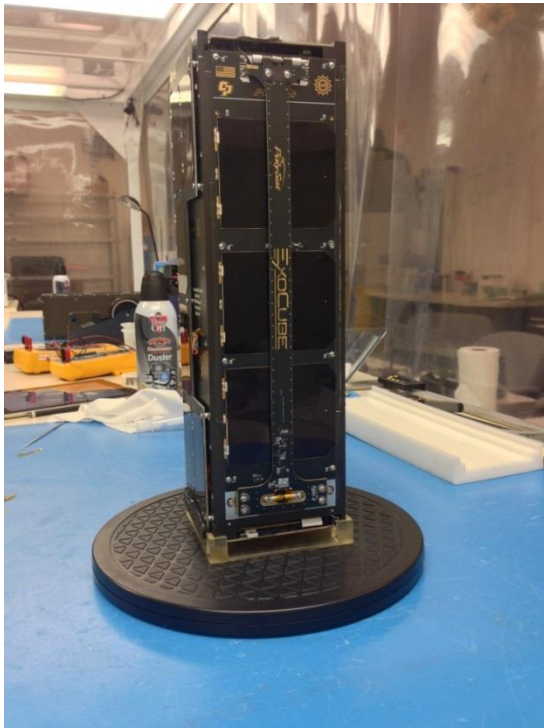
Courtesy of Lara Waldrop,
Univ. of Illinois

Missions and Opportunities

The ExoCube mission (PI John Noto, Scientific Solutions)



- California Polytechnic State (Calpoly) University built 3U CubeSat bus
- 440x675km Orbit altitude, 98 degree inclination
- ELaNa-X SMAP Delta II launch January 31, 2015
- 6-12 month operation (ExoCube ended up operating ~7 months)



Delta II out of Vandenberg, CA



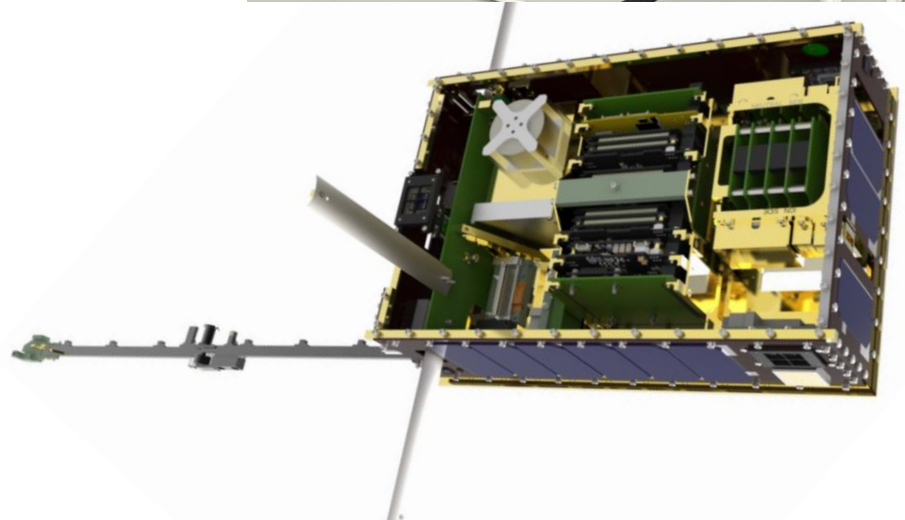
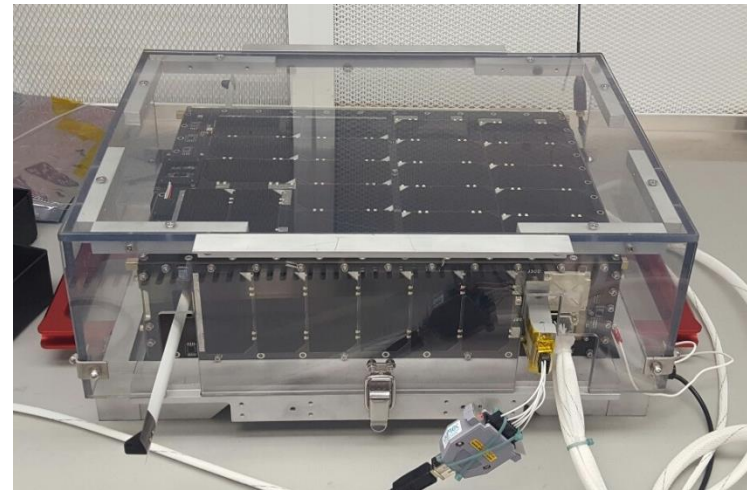
DELLINGER

A Path to
Compelling Science

The Dellinger mission (NASA Goddard Space Flight Center)

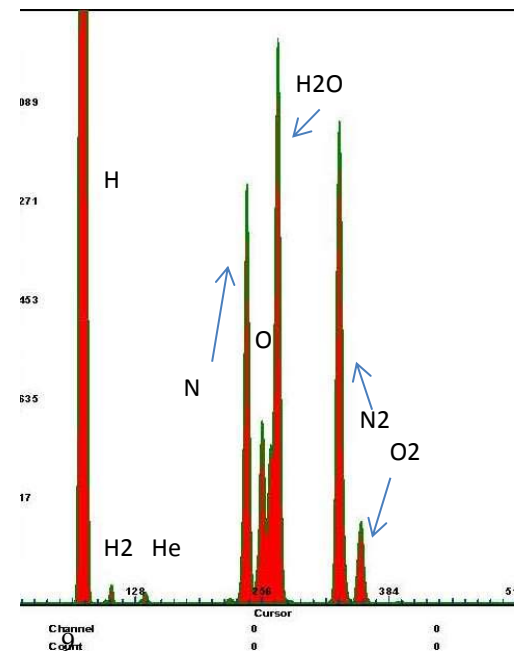
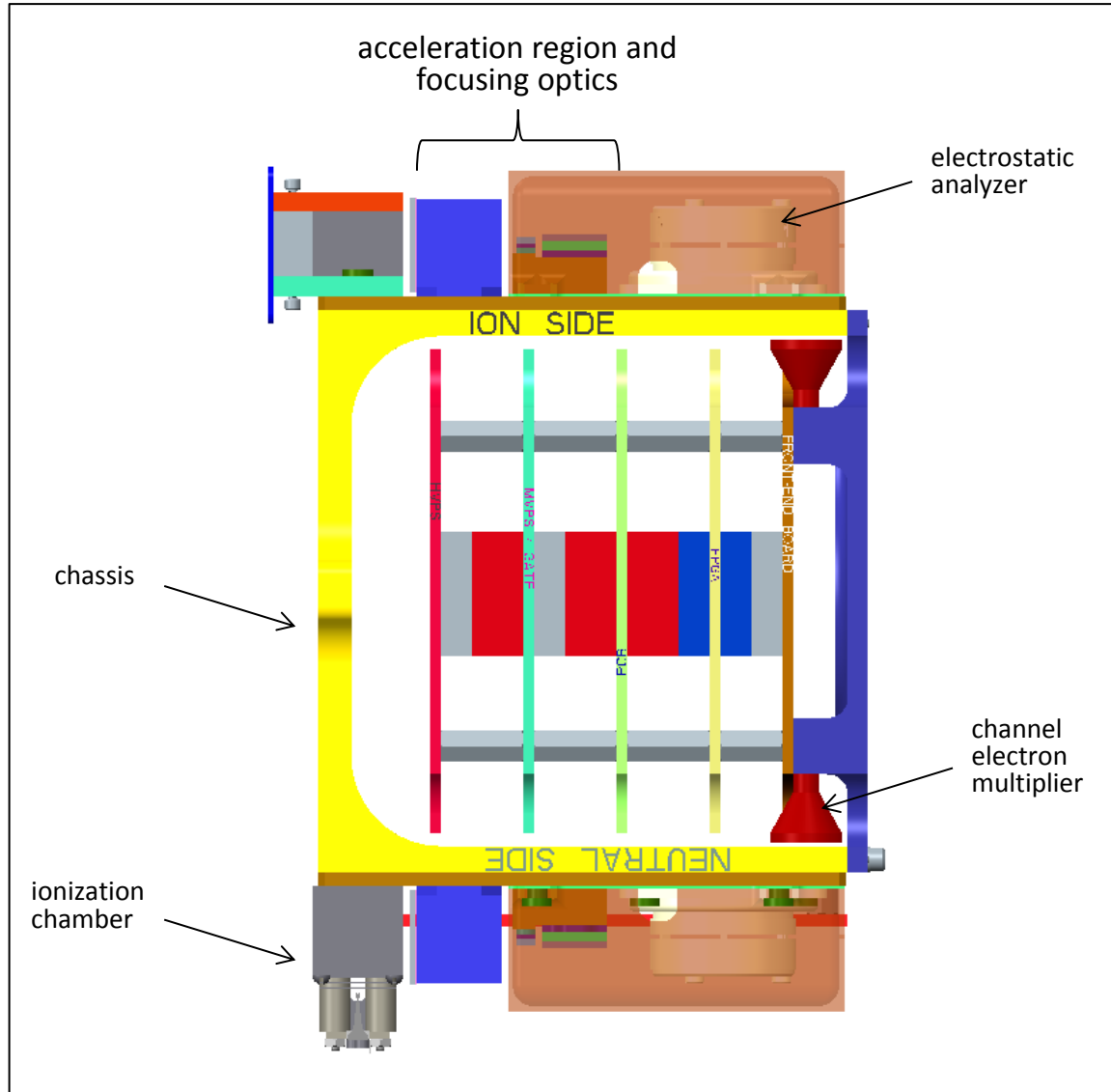
Goddard's internal project to design, build, test and fly a 6U CubeSat carrying 2 GSFC science instruments (Science Magnetometers and **Ion-Neutral Mass Spectrometer**)

- 3-axis stabilized GNC system
- Launch 2017



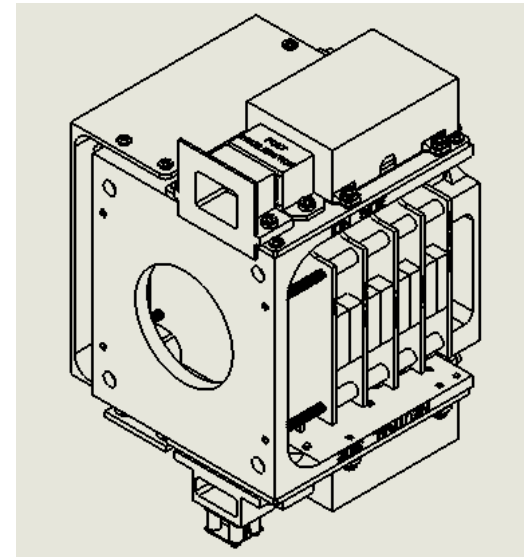
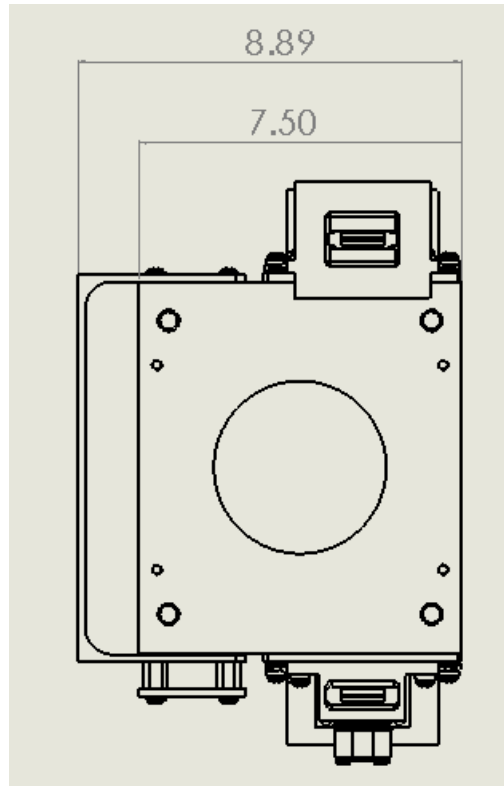
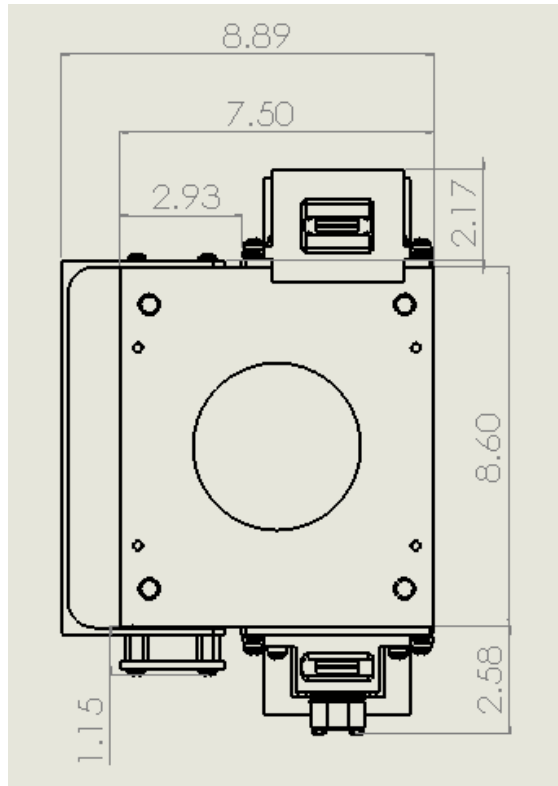
INMS DEVELOPMENT

Brief Description of INMS



**Example TOF spectrum:
measurements of neutral
species from H to O₂**

Dimensions



INMS Principles of Operation

- Pre acceleration voltage, V , gives all ions the same energy, $E = qV$, much greater than initial energy dispersions dE .
- Relatively speaking, the energy dispersion is small in comparison with the total energy after pre accelerating, so we can treat the ions as though they all have the same energy.
- Thus the ions are ordered in velocity according to their mass on the basis of the simple formula:

$$E = \frac{1}{2} m v^2$$

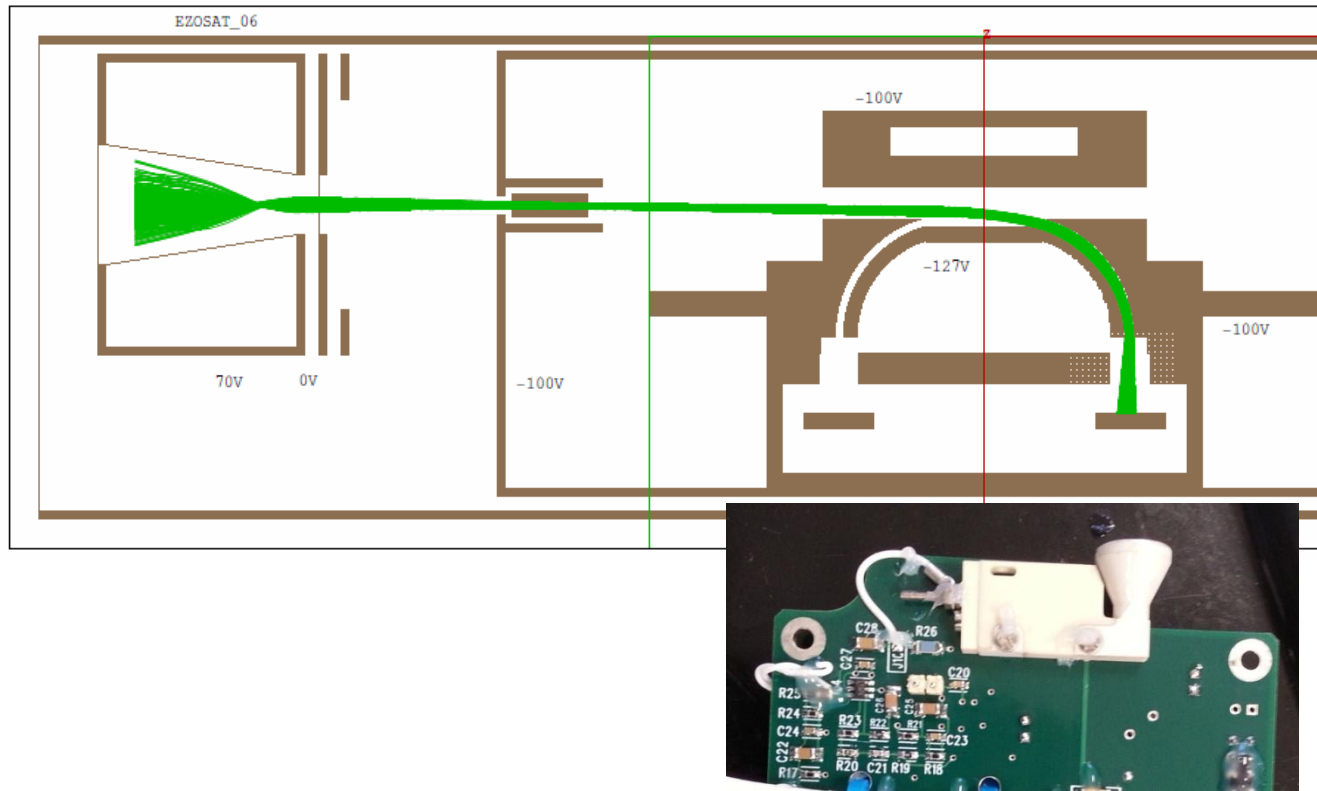
- Measuring the velocity of each ion - with time of flight over a distance d - gives the mass of the ion according to:

$$M/q = 2 \times E/q \times \text{TOF}^2 / d$$

- The mass resolution is limited by uncertainties in energy dispersion, time resolution and time of flight path.

Principles of Operation

- The accelerated ions are focused through the electric gate into an electrostatic analyzer (ESA).
- The ESA is tuned to the proper energy pass band set by the pre acceleration voltage blocking out of band particles, as well as attenuating any UV light.
- Ions are detected at the output of the ESA by a CEM detector marking the stops for the time of flight measurements.



INMS Specifications

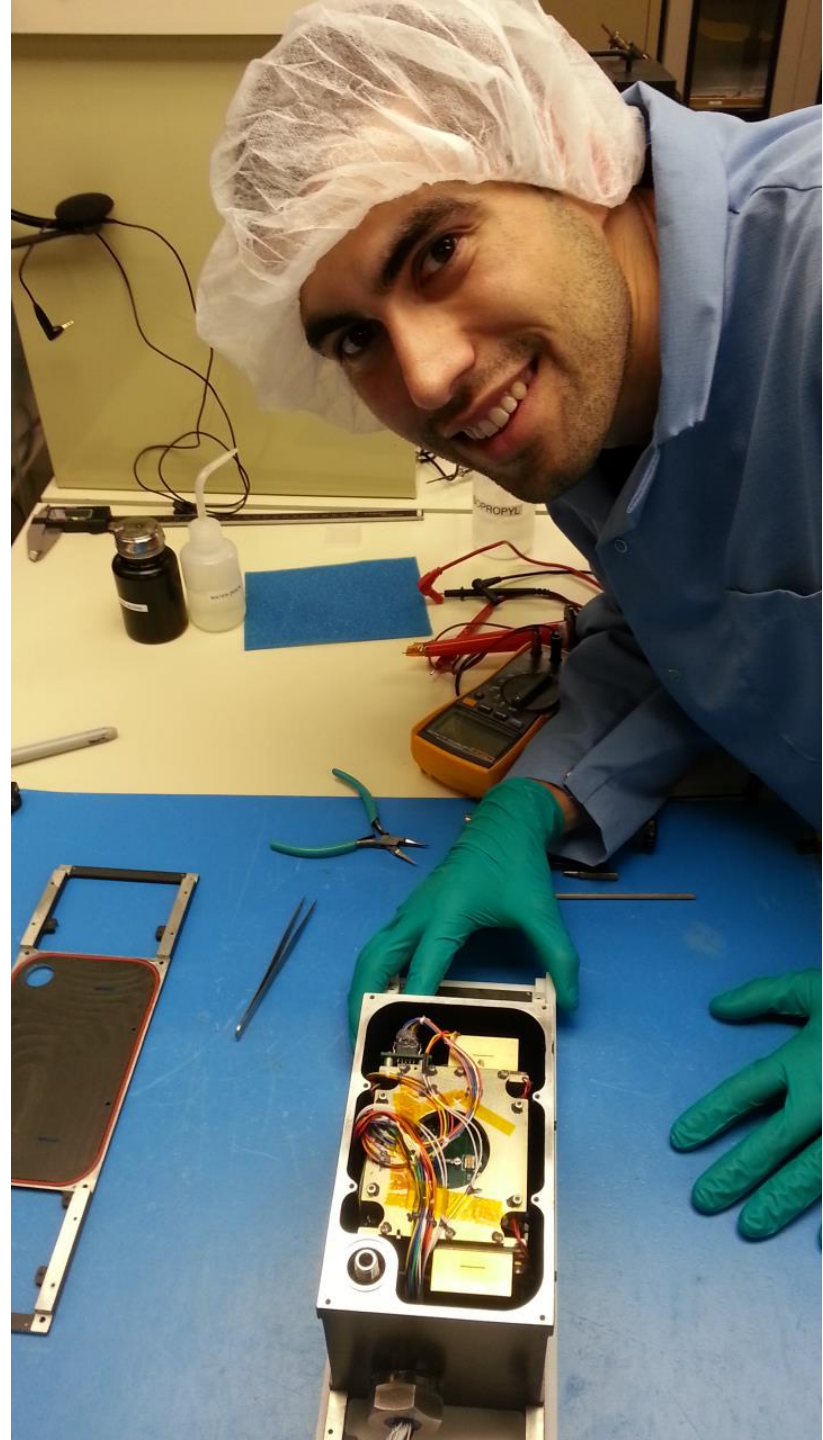
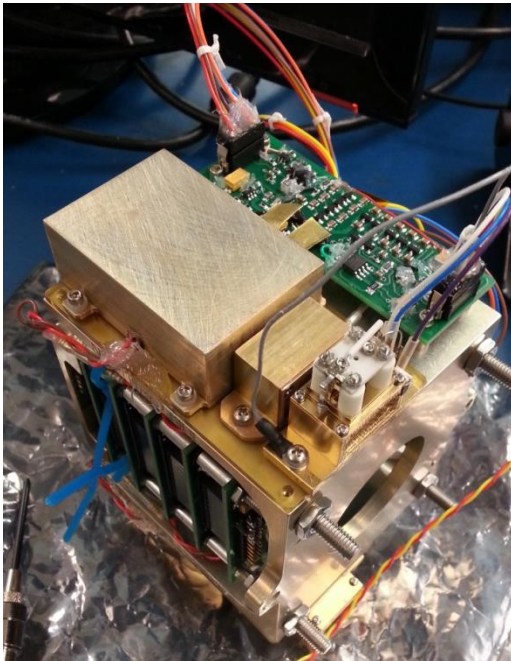
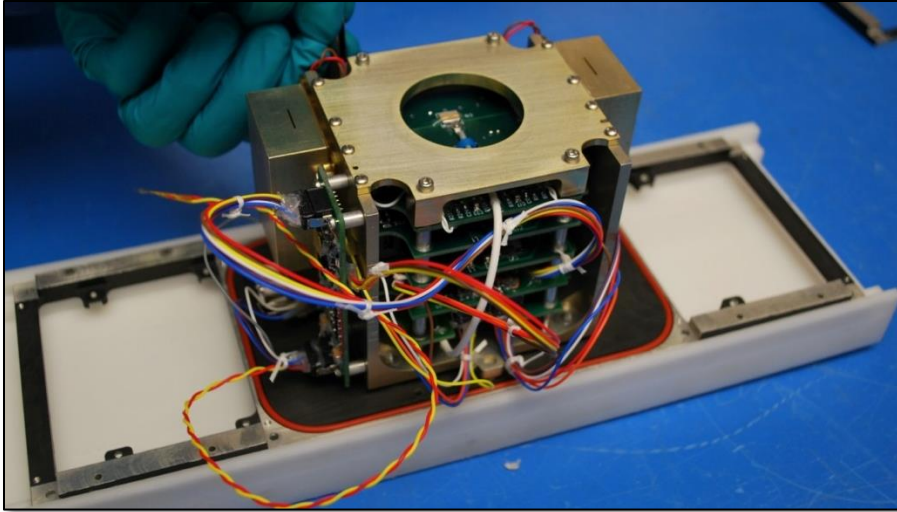
Engineering Specifications	
FOV (effective)	$\pm 20^\circ \times \pm 10^\circ$ around ram
Volume	$\sim 13.5\text{cm} \times 9\text{cm} \times 9\text{cm}$
Mass	600g
Power	1.8W (Ions+Neutrals), 1.3W (ions only)
Data (raw data, no compression)	1.3kbps (1s sampling)
Electrical Interface	$\pm 5\text{V}$, +3.3V, I2C and SPI serial communication

Science Specifications	
FOV (effective)	$\pm 20^\circ \times \pm 10^\circ$ around ram
Density Dynamic Range	$\sim 10^5$
Mass Dynamic Range	1-40 amu
Mass Resolution	$M/dM \sim 12$
Energy Dynamic Range	Float 1-200v, ESA 1-50v
Count Rate	1Mcps
Sampling time rate	0.1s-10s (1s default setting)



ExoCube Results

Integration at CalPoly

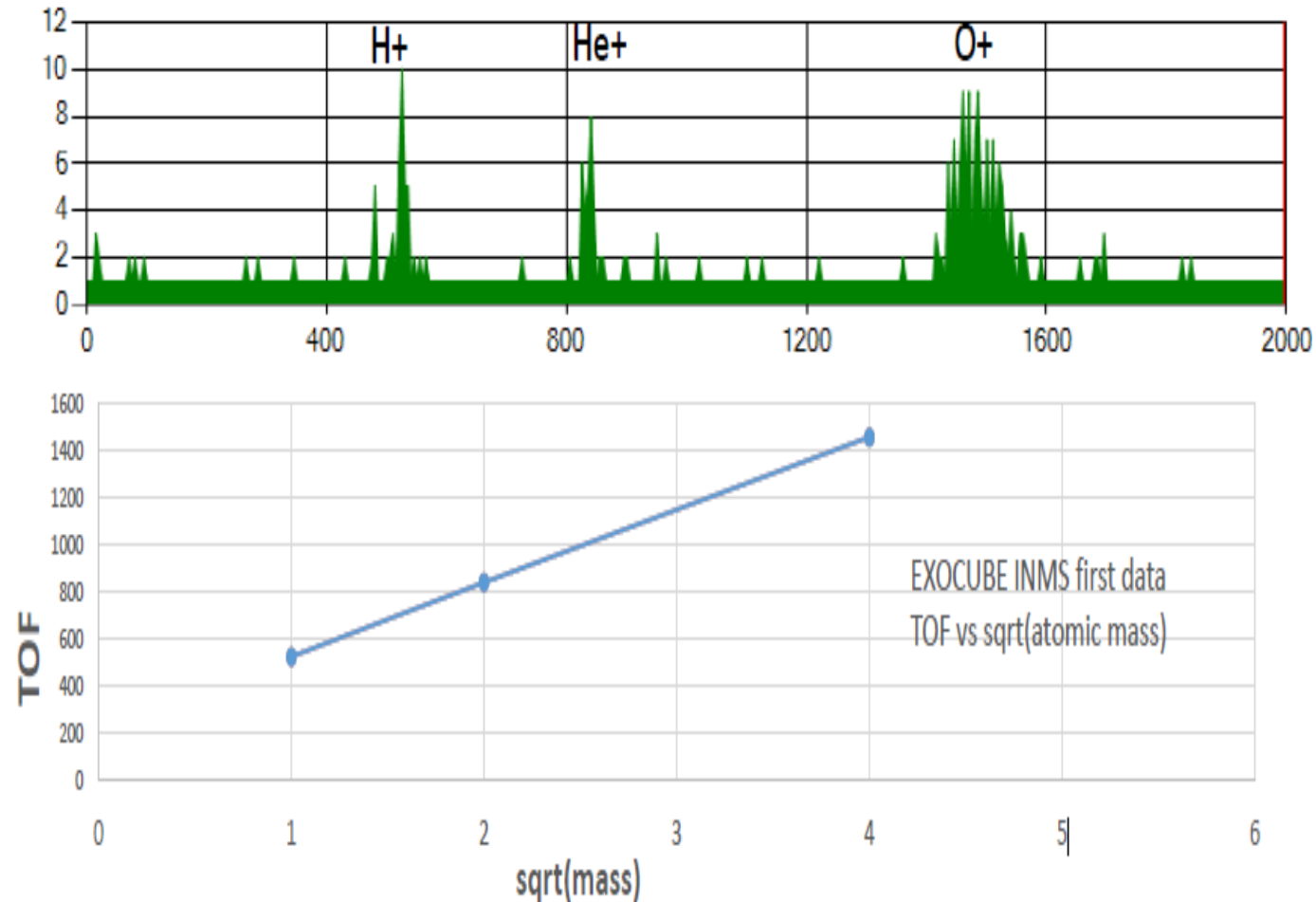


ExoCube Mission Operations

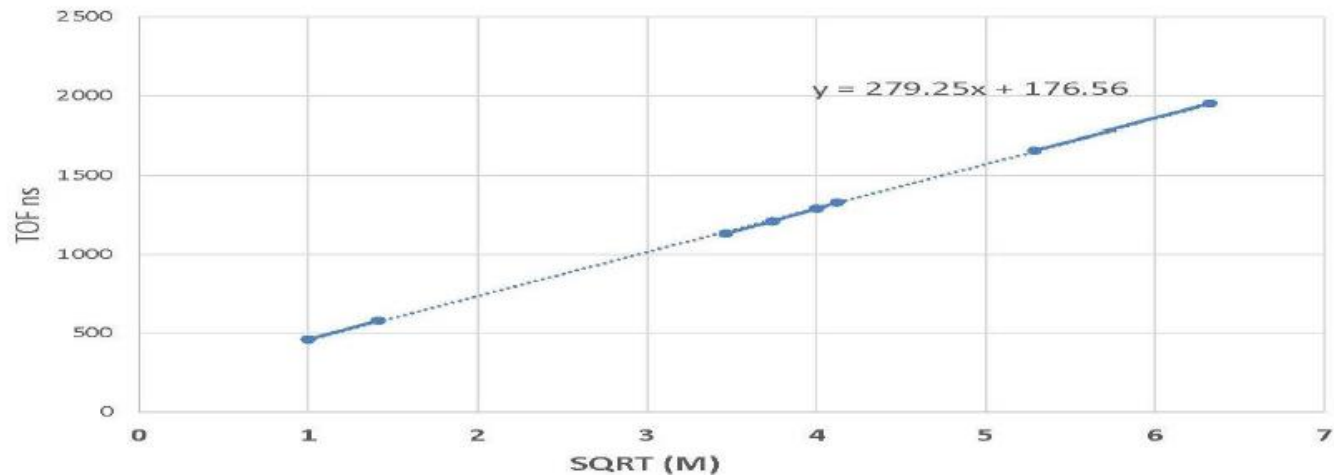
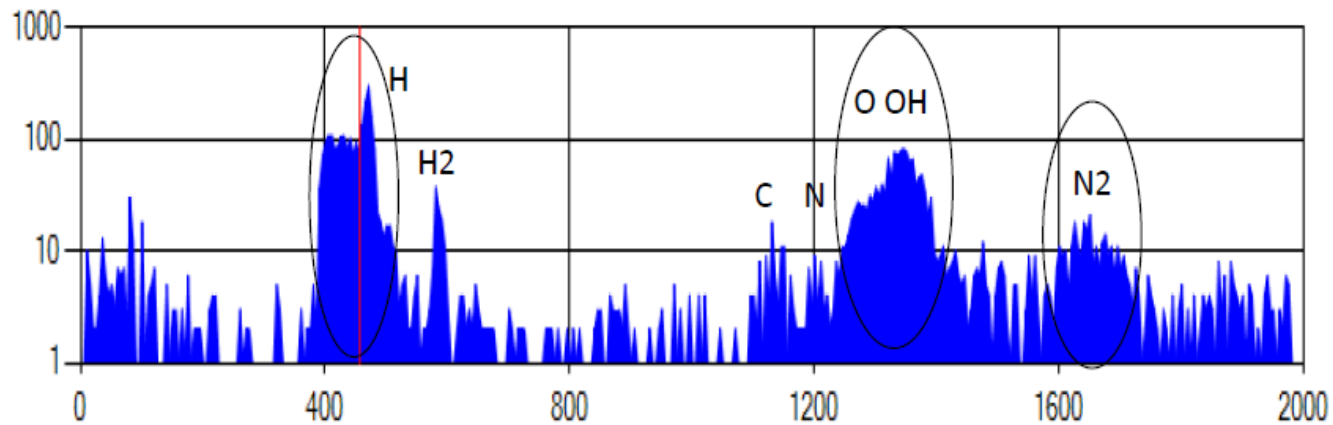
- Failed attempts to deployed antenna via burnwire
 - Weak and infrequent signal due to un-deployed antenna
 - Acquired passes using SRI dish antenna, ~2 passes per week (could not communicate with CalPoly Yagi antennas)
 - Frequent rebooting issues
- Reprioritize instrument checkout and technology demonstration before gravity gradient boom deploy and attitude control procedure

ExoCube INMS:

First Flight Ion Spectrum, May 20 2015



ExoCube INMS: Flight Neutral Ambient and Outgassing Spectrum, July 15 2015



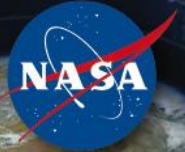
ExoCube INMS summary

- INMS functionality testing showed the instrument in good health.
- All voltages and functionality were validated in flight.
- ExoCube INMS flight spectra are consistent with those obtained in the lab.
- Unable to obtain science data due to loss of spacecraft communications.
- Successful technology demonstration brings INMS to TRL 8!

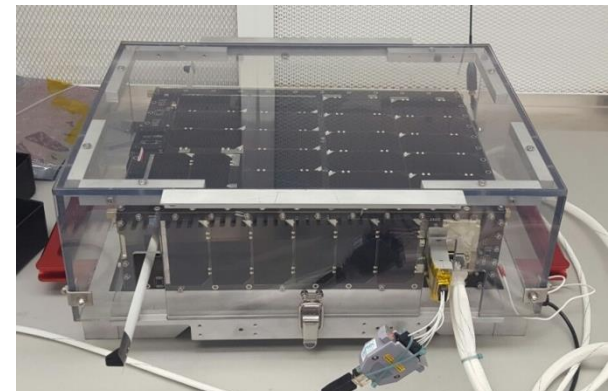
ONGOING DEVELOPMENT EFFORTS

DELLINGR

A Path to Compelling Science

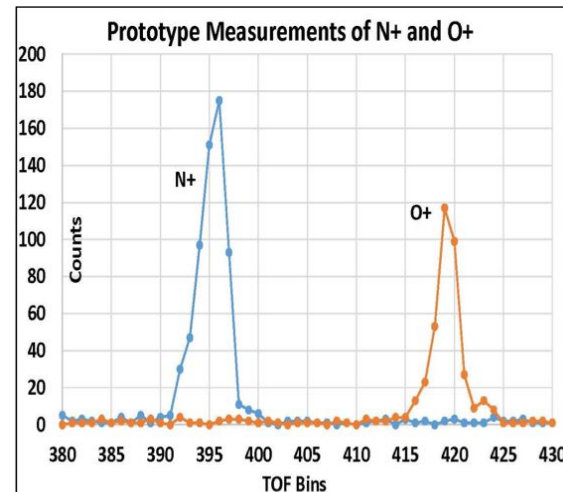


- Delivered July 2016, Launch scheduled for mid-2017
- INMS upgrades from ExoCube
 - DELLINGR features separate ESA, float and steering voltages for ions vs. neutral
 - CEM detectors operating at lower HV
 - Ionization power supply re-designed to control ionizer optics
 - ESA power supplies have higher ceiling expanding the energy dynamic range of instrument
 - Adjustable steering voltages to control throughput
 - Higher HVPS ceiling for increasing detectors lifetime
 - Added protection against arcing



Ongoing and Future Upgrades

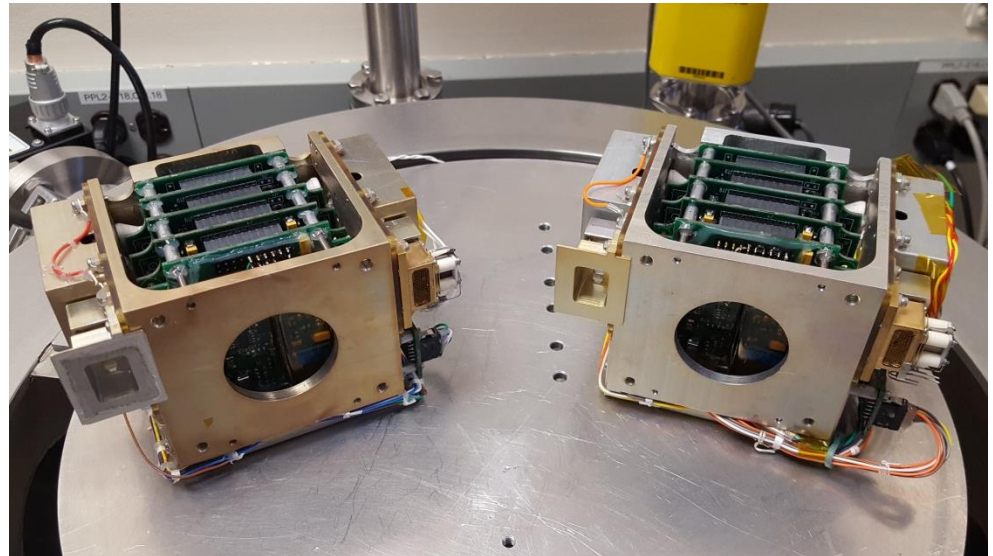
- Upgrades ongoing on INMS
 - Increased effective FOV
 - Higher mass resolution techniques being incorporated
 - Modular approach for flexibility
- Neutral wind and ion drift capabilities being developed for specific applications
- Neutral wind IT measurements are highly sought out in the science community and for atmospheric drag calculations
 - Minimal empirical measurements to date
 - None directly measured with mass distributions
- Ion drifts measurements also highly sought to determine dynamics and coupling of the IT environment



Future Missions

- ExoCube 2 - NSF Rapid Proposal planned for 2017 for follow up mission
- NASA GSFC Sounding Rocket launch 2018
- Constellation mission are a prime target to maximize science and business return
- Looking for partners to increase the flight opportunities for INMS and its upgraded successors

**“Ready-to-fly”
design available**



Back up slides

S/C Complications

- s/c tumbling resulted in extended periods of especially poor communications
- Due to weak comm links with s/c, our longer command sequences were broken down into a series of shorter command sets
- Ongoing problems with setting and maintaining accurate s/c clock, sometimes our commands were executed out of sequence
- Occasionally, errors in time tagging resulted in commands not being sent
- Unfortunately, pointing knowledge is not available for INMS data

